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Title: Climate variability and fill rate impacts on downstream flows from the Grand Ethiopian Renaissance Dam

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Climate variability and fill rate impacts on downstream flows from the Grand Ethiopian Renaissance Dam

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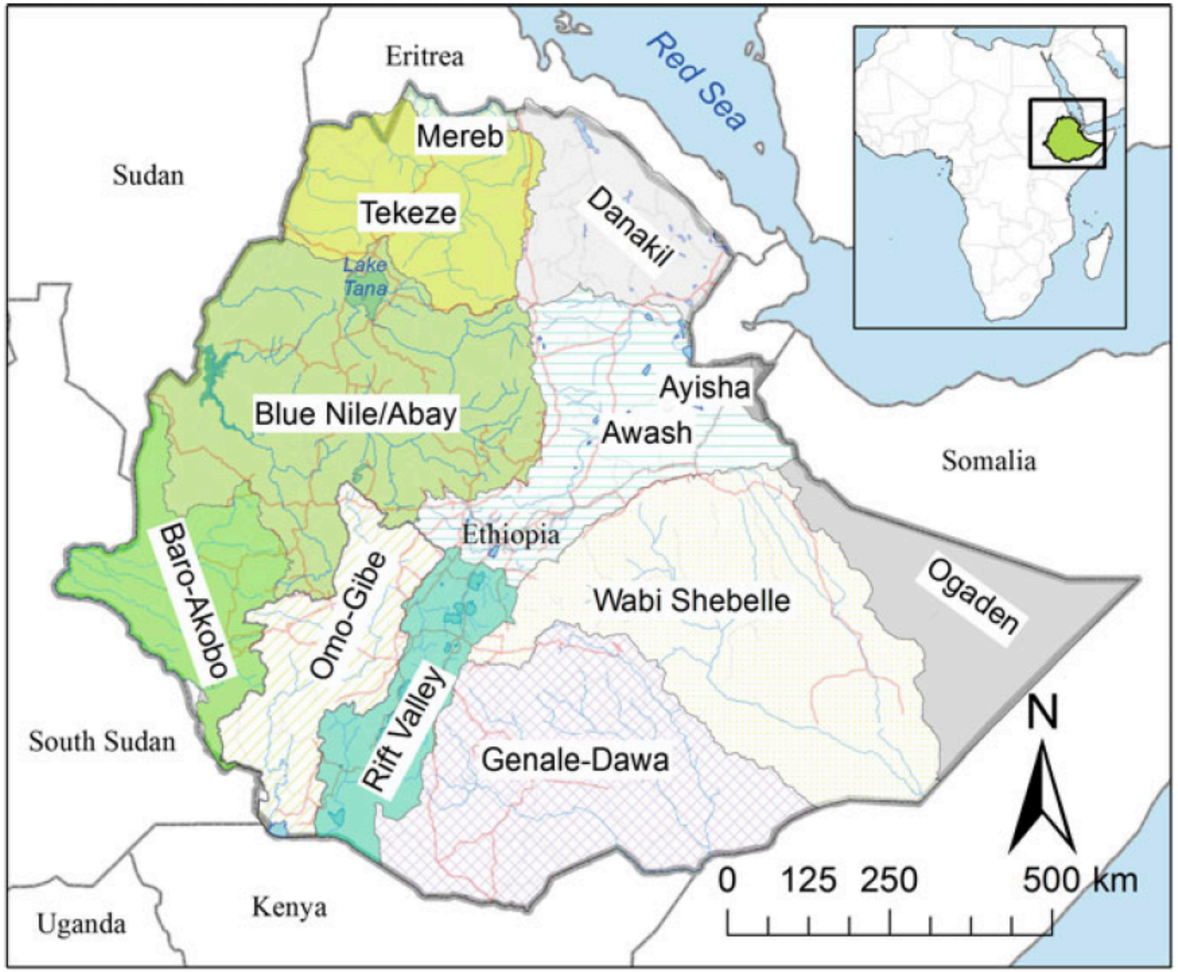
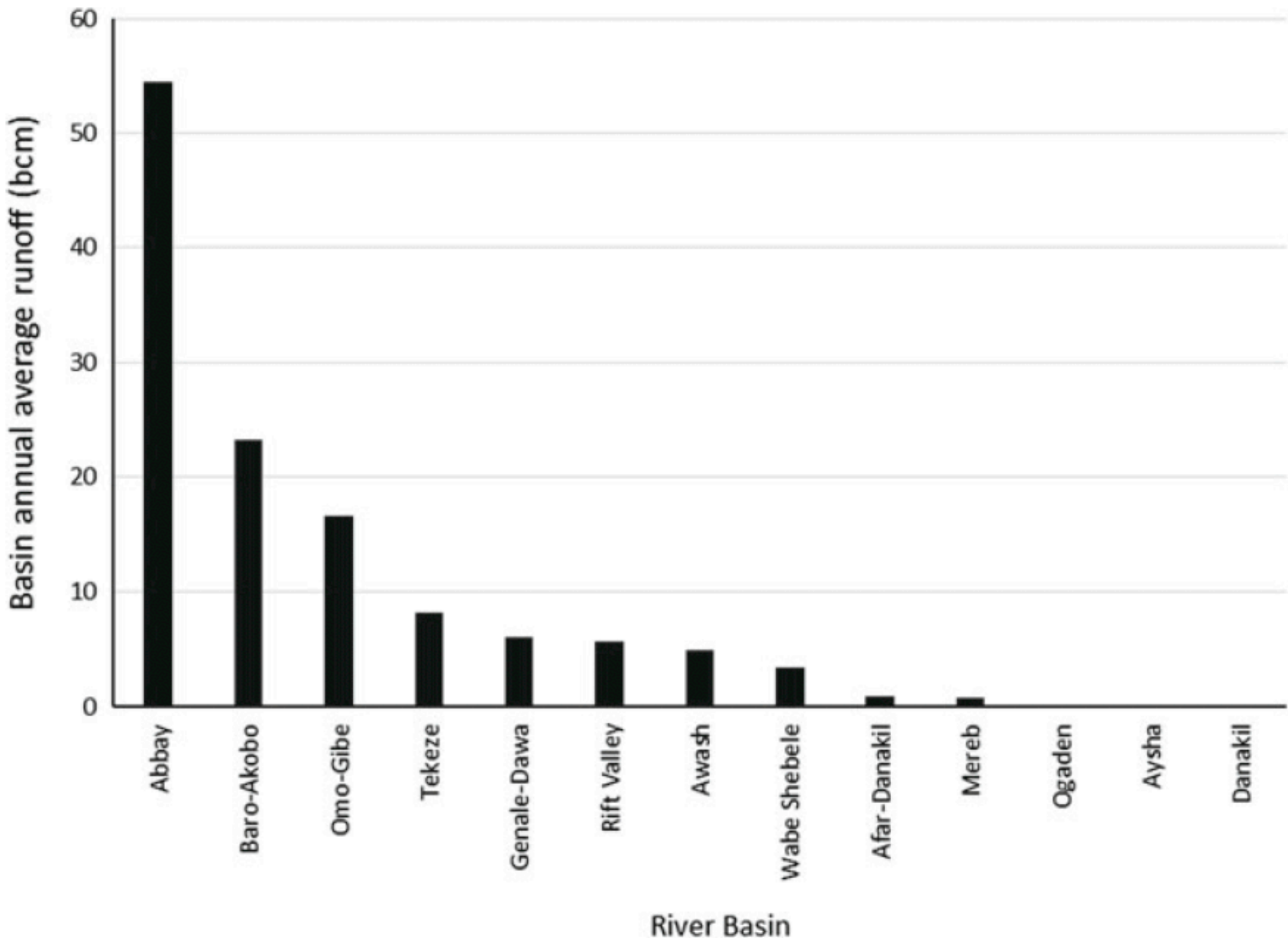
Background: Major watersheds within Ethiopia

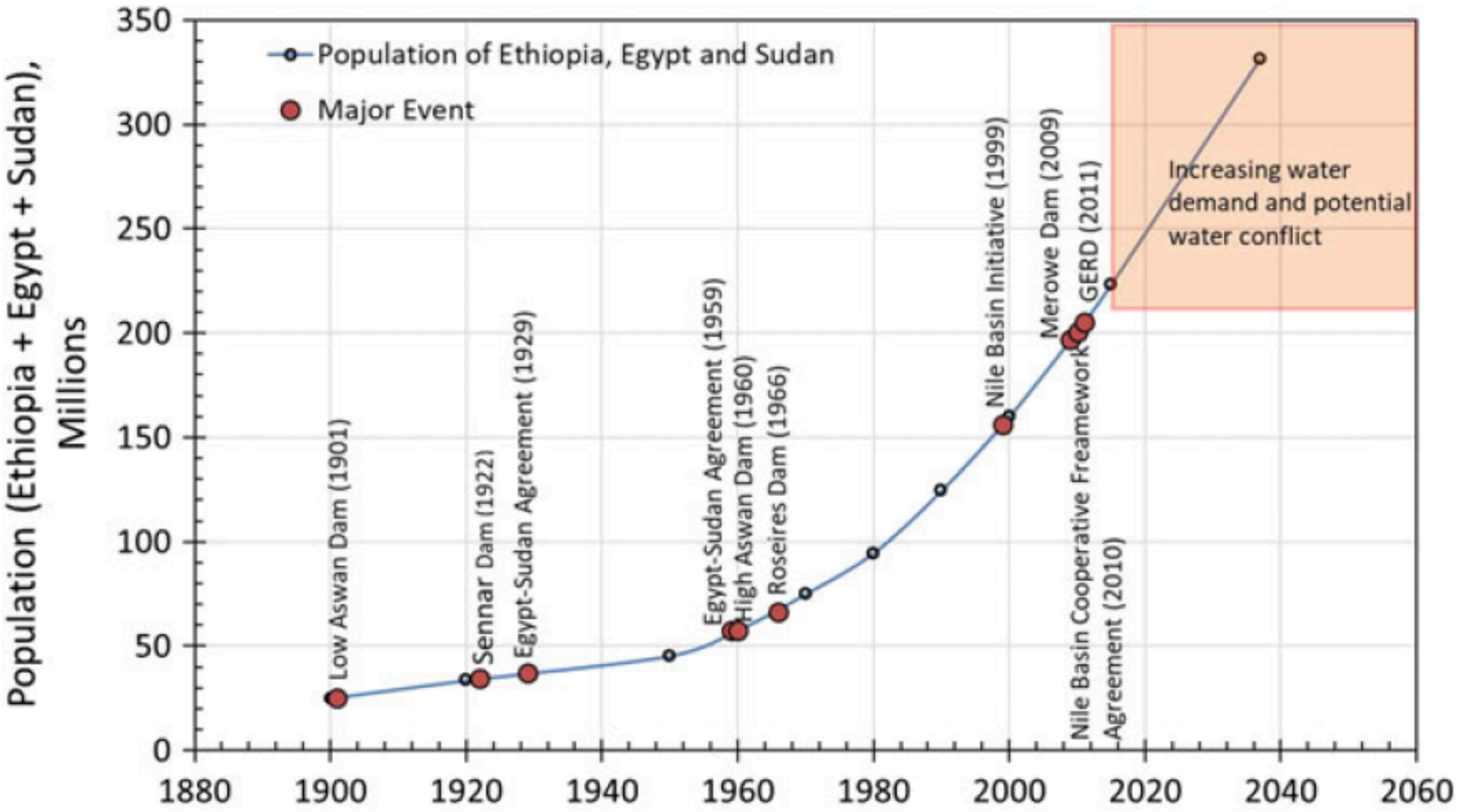




Abtew and Dessu, 2019

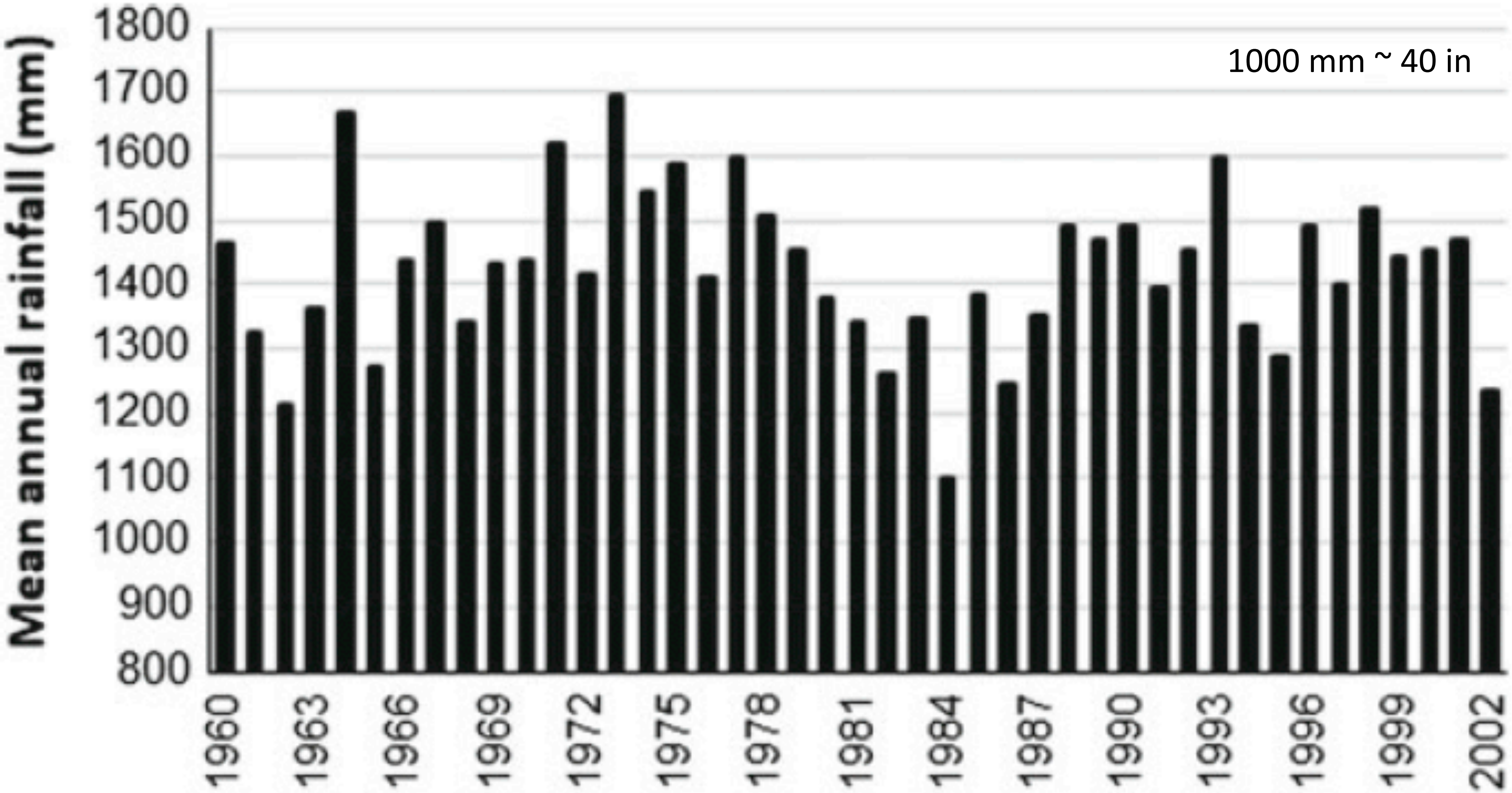
- Blue Nile/Abbay contains the largest amount of water in Ethiopia
- Accounts for 10% of Nile drainage area, but 60% of streamflow
- Historically, all water goes to Egypt & the Sudan through prior agreements from 1960s

Background: regional population growth pressures increased access to water resources



Abtew and Dessu, 2019

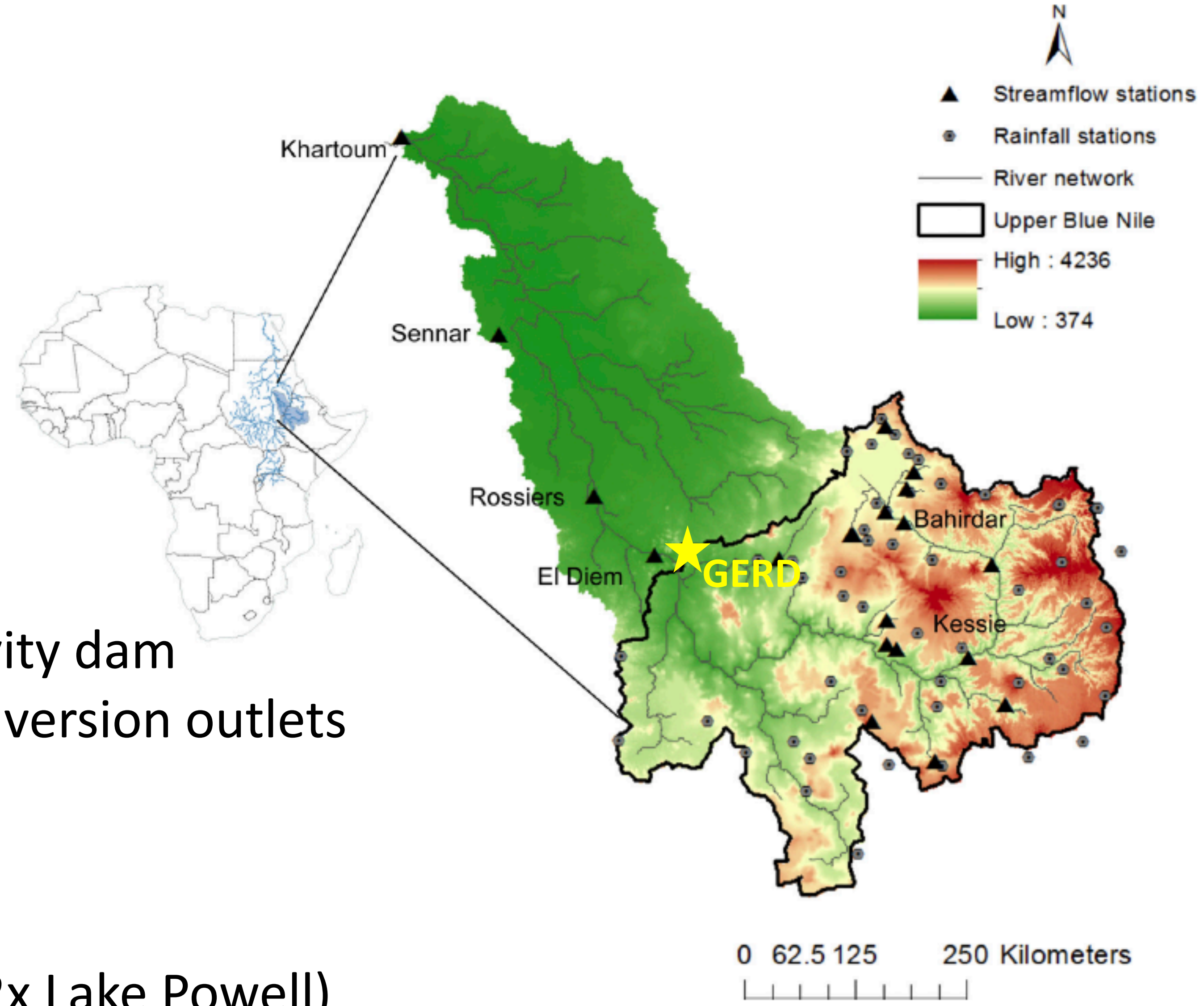
Background: water plentiful in Blue Nile Basin, but strong seasonal signature



- Most rain (>95%) occurs May-Nov

Abtew and Dessu, 2019

Background: the Grand Ethiopian Renaissance Dam



- Roller-compacted concrete (RCC) gravity dam
- Two power houses, 16 penstocks, 4 diversion outlets
- 155 m height, 1800 m length
- Mean Energy per year = 15,700 GWH
- Mean annual inflow 45-50 bcm
- Reservoir storage capacity 63 bcm (~2x Lake Powell)

Taye et al., 2015

Problem: what should the fill rate of the dam be (previous studies)?

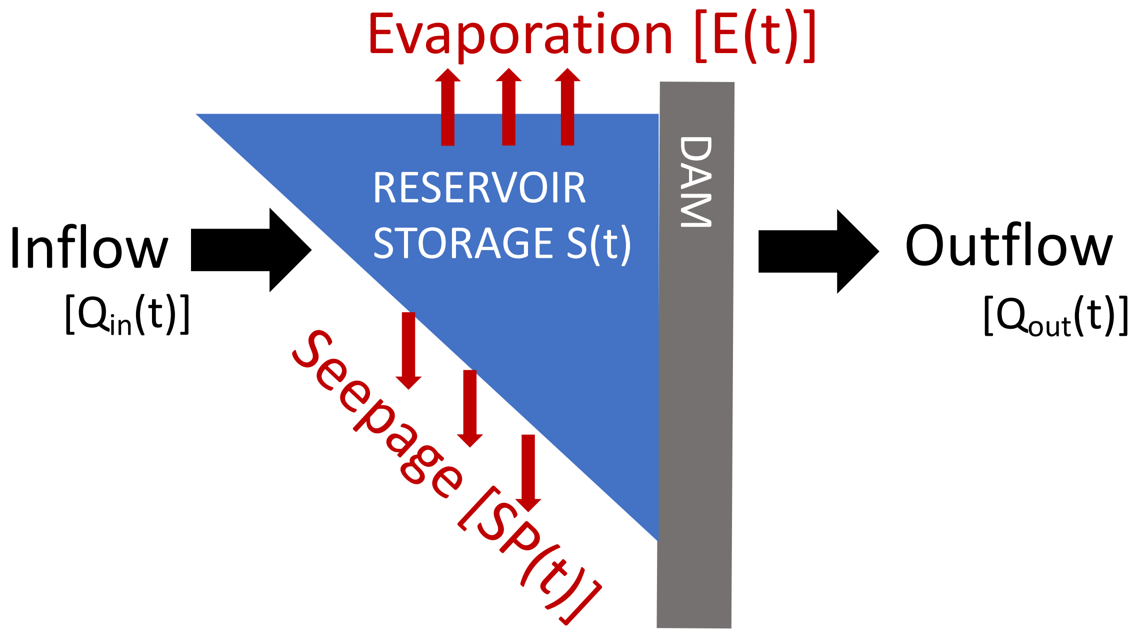
Average impact of 5, 6 & 7 year fill periods (Tesemma et al., 2014)

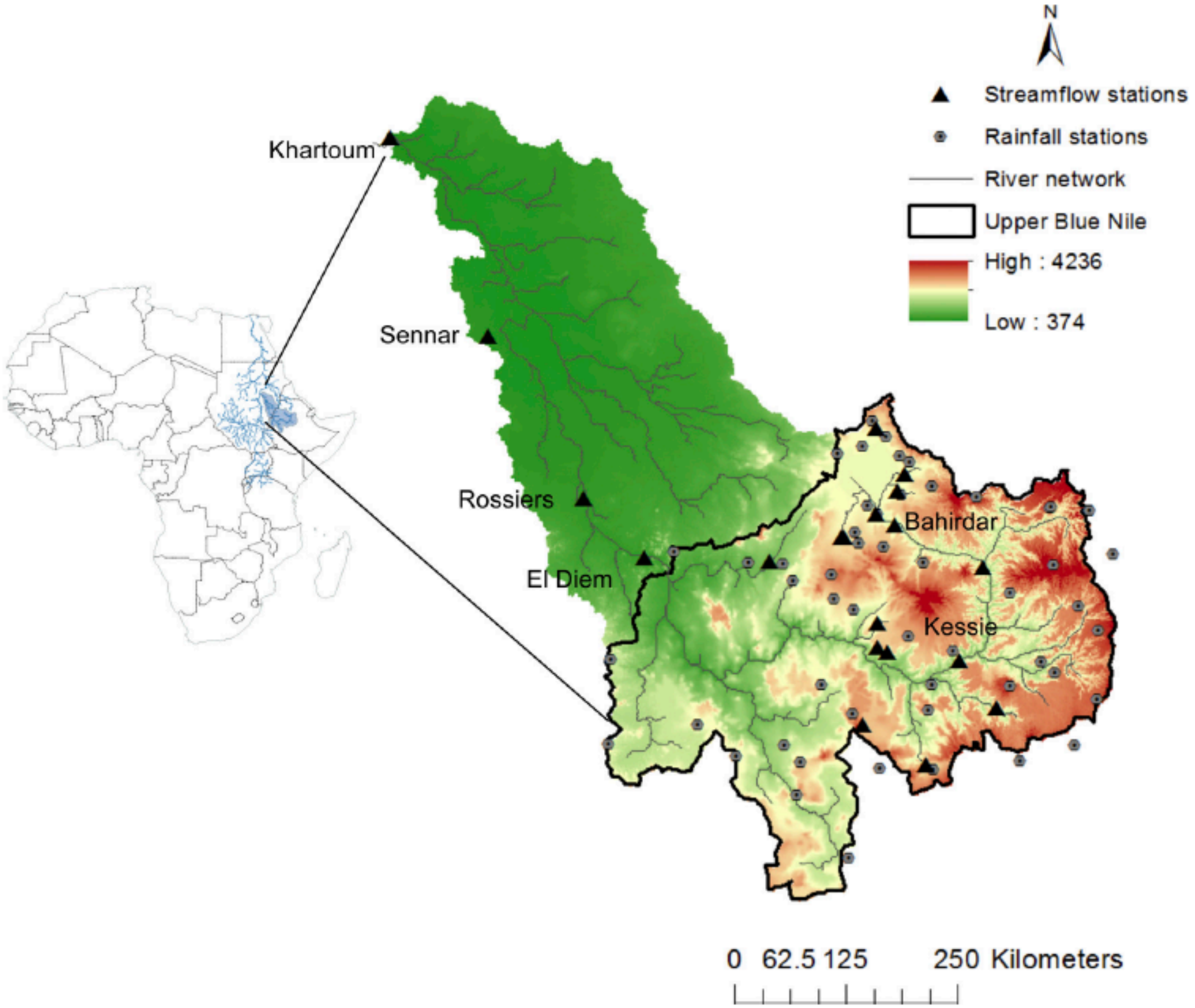
Country	Hydropower (%)	Flow Reduction (%)	Location
Ethiopia	400	--	--
Sudan	14.47	-3.3	El-Diem (Ethiopia-Sudan border)
Egypt	--	-8.02	Aswan Dam inflow
Egypt	-8.34	-3.01	Aswan Dam outflow

Impacts on Blue Nile flow for different fill rates (Keith et al., 2014)

Fill Rate (years)	Flow Reduction in Blue Nile
5	-4.22
10	-8.77
15	-13.15
20	-16.18
25	-20.72

- Failed to account for future climate or adequately represent high or low flow periods in analysis
- Did not use realistic reservoir operating rules in modeling scheme



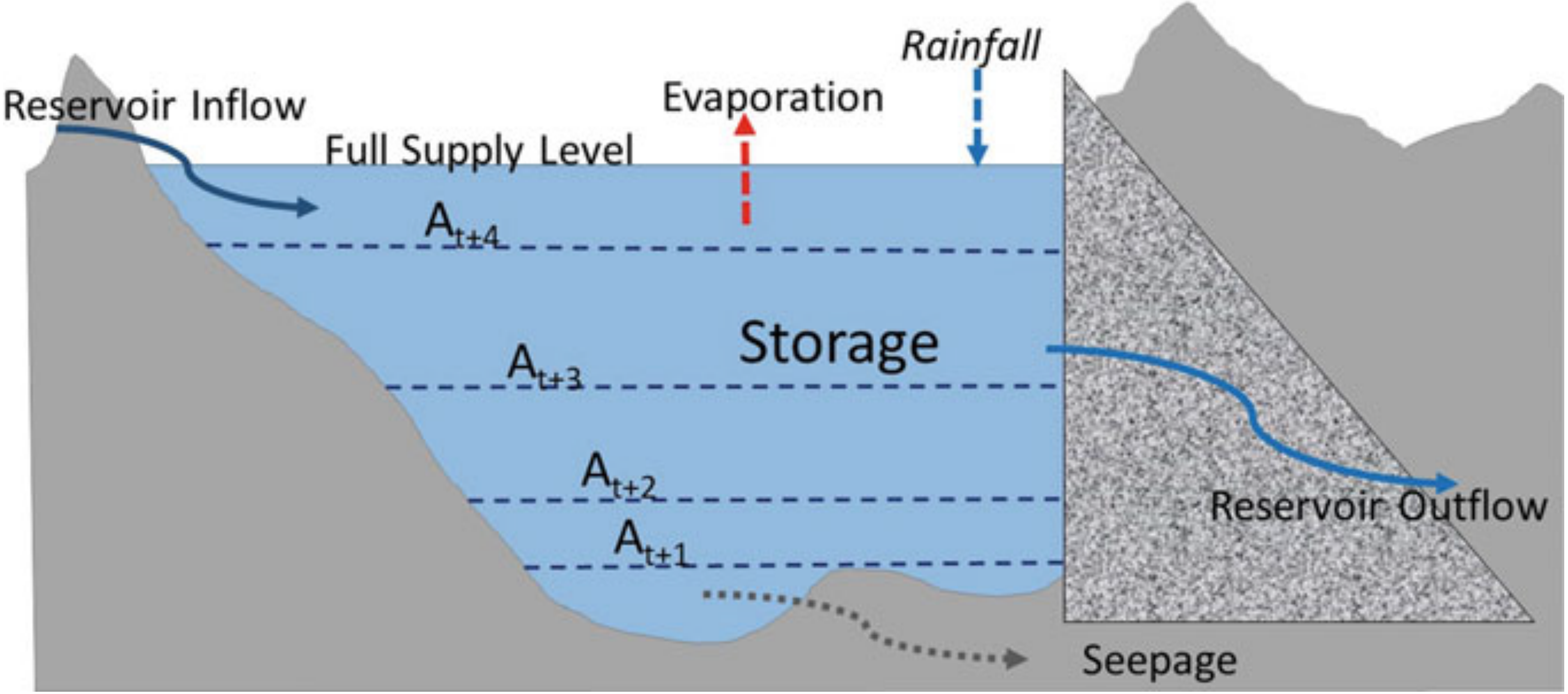


Governing Equations

- $Q_{out}(t) = Q_{in}(t) - E(t) - S(t)$
- $S(t) = S(t-1) + Q_{in}(t) - Q_{out}(t)$

Taye et al., 2015

Seepage and Evaporation Calculations



Abtew and Dessu, 2019

A(t) = Reservoir Area
S(t) = Reservoir Storage
E(t) = Reservoir Evaporation
ER = Evaporation Rate
SR = Seepage Rate

Reservoir Evaporation

$A(t) = -0.137*S^2(t) + 35.904*S(t) + 52.563$

$E(t) = A(t)*ER$

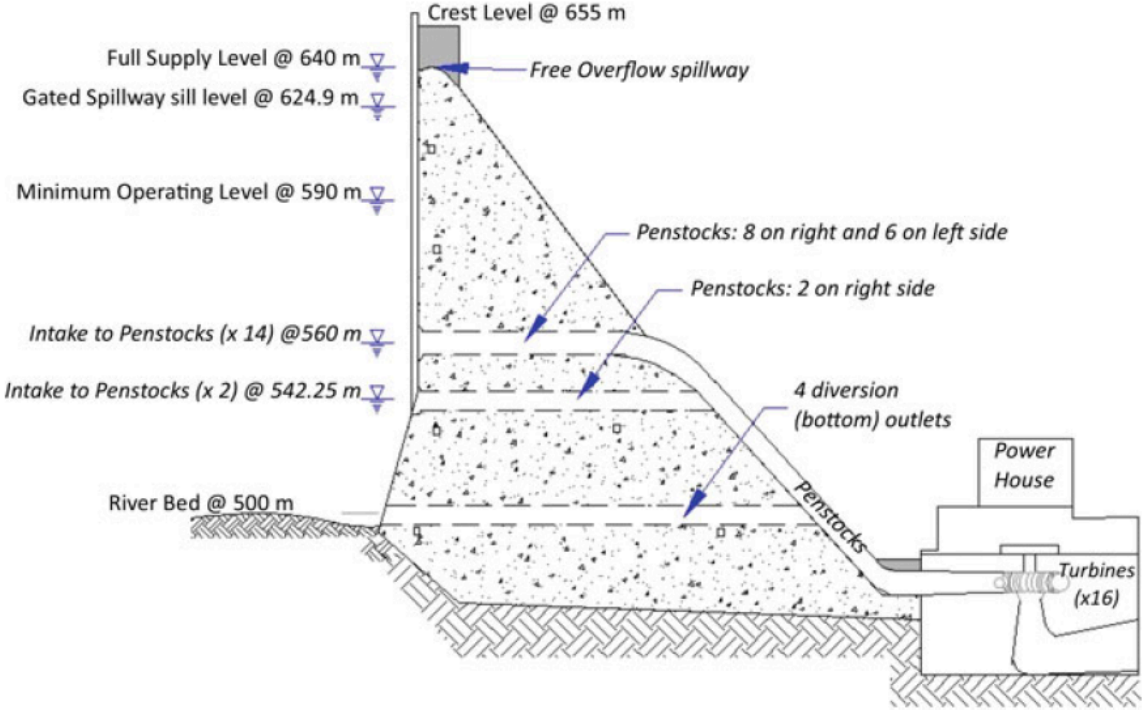
0.73 m/yr (Mulat et al., 2014)

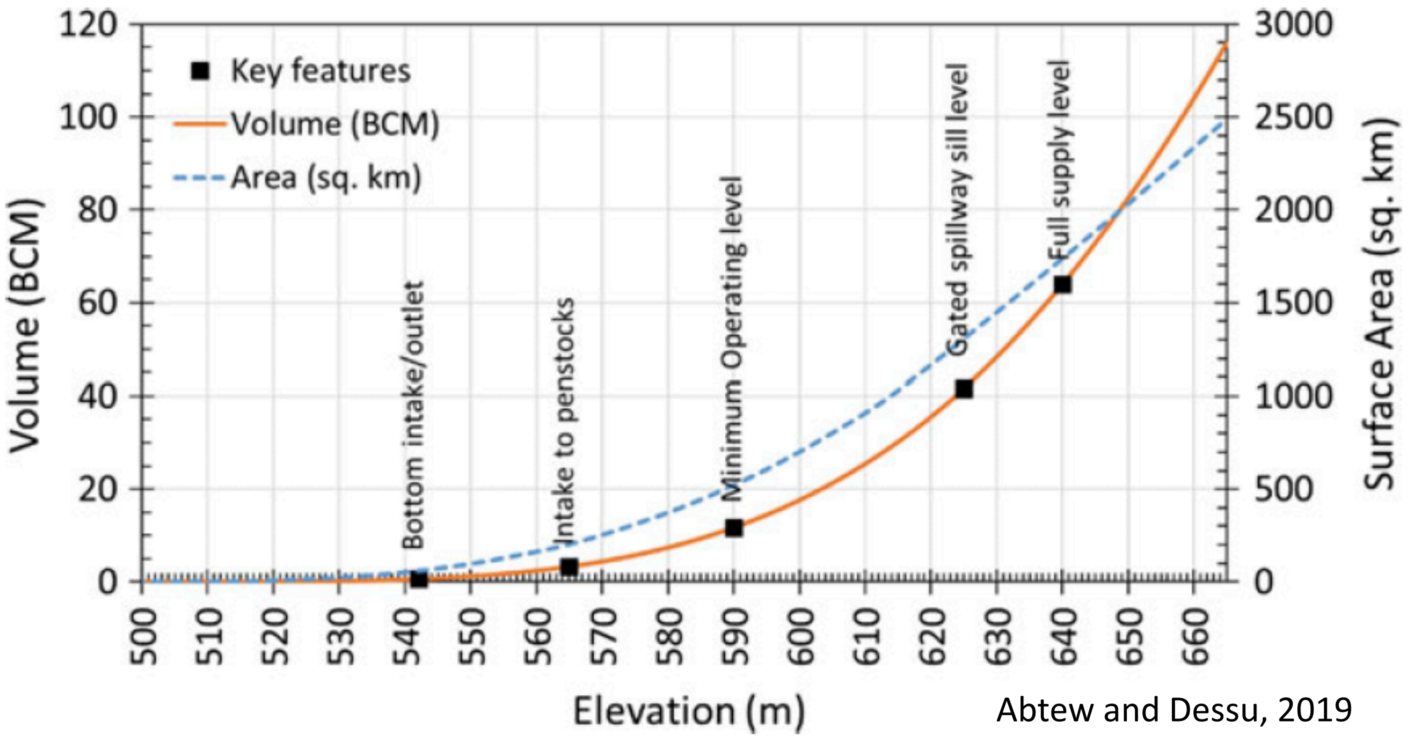
Reservoir Seepage

$SP(t) = SR*S(t)$

SR = 2.134 mm/day

Annual GERD Reservoir Operating Rules





Abtew and Dessu, 2019

- Storage <12 bcm (Minimum Operating Level), must release at least 10 bcm downstream
- Storage >12 bcm (Minimum Operating Level), must release at least 25 bcm downstream
- Can take water out of storage to meet these requirements
- Goal to fill 1/n x 100% of max storage capacity every year where n is targeted fill period
- Determine if downstream flow compact of 43 bcm/yr being met

Model Scenarios

GERD Inflow Data Sources:

- Historical (1960-1999)
- **Future RCP 4.5 (2030-2059)**
- Future RCP 8.5 (2030-2059)
- Historical JULES (1979-2016)
- Historical FLDAS (1982-2018)
- Historical JULES + FLDAS (1982-2016)

Liersch et al., 2017

Wahl and Tavakoly, 2019

Flow Conditions:

- Wet
- Normal
- Dry

*Represented using Gamma Distribution to bias the data

Fill Rate

- 5-year

(most aggressive)

- 10-year
- 20-year

(least aggressive)

Liersch et al., 2017

-Inflow based on Soil and Water Integrated Model (SWIM) output driven by meteorological observations (historical) or suite of 10 GCMs (RCP 4.5 & RCP 8.5)

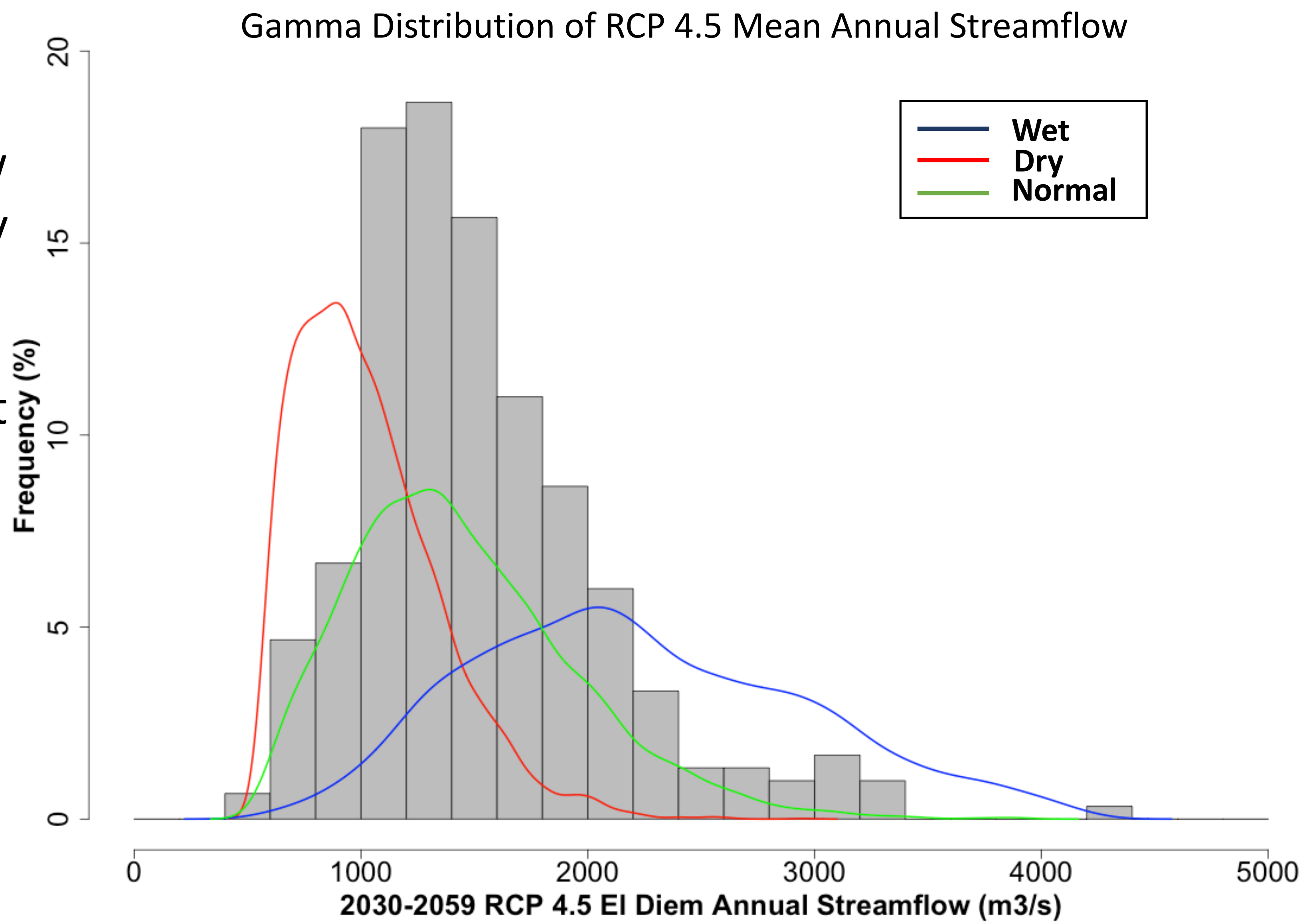
Wahl and Tavakoly, 2019

-Inflow based on Land Surface Model outputs driven by meteorological observations and river routing models

*All models calibrated using observed streamflow data on Blue Nile at El Diem (~20 km from GERD site)

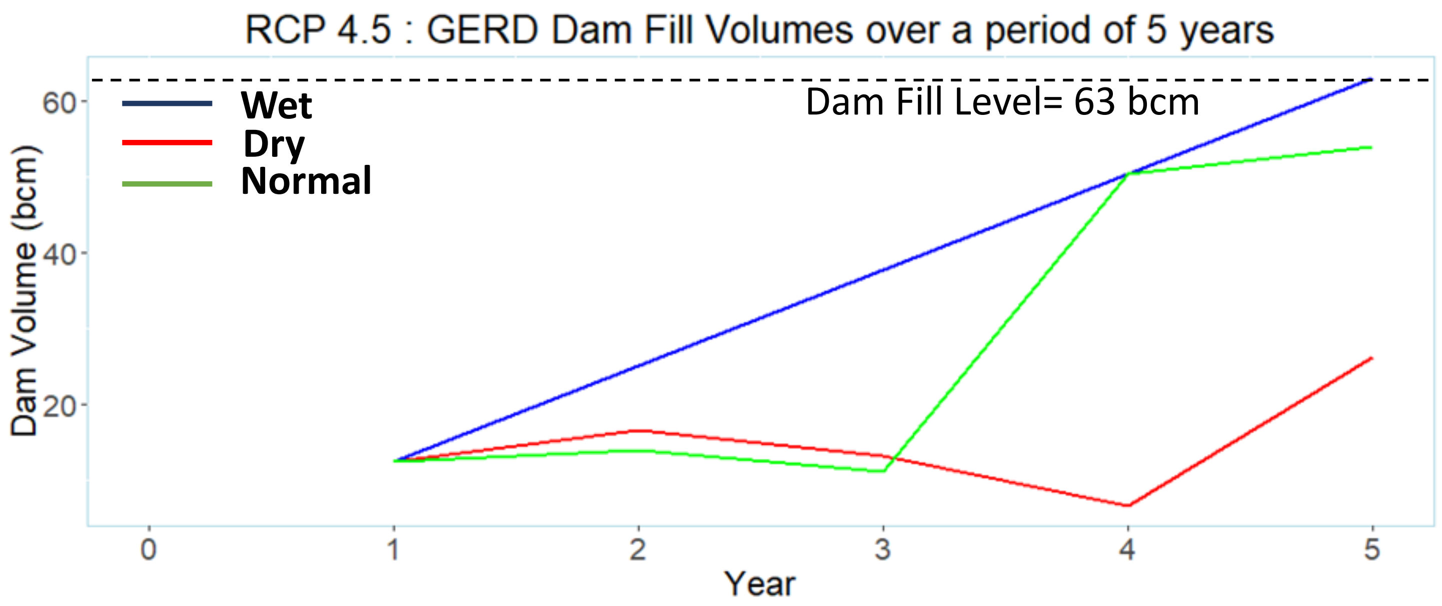
Inflow data

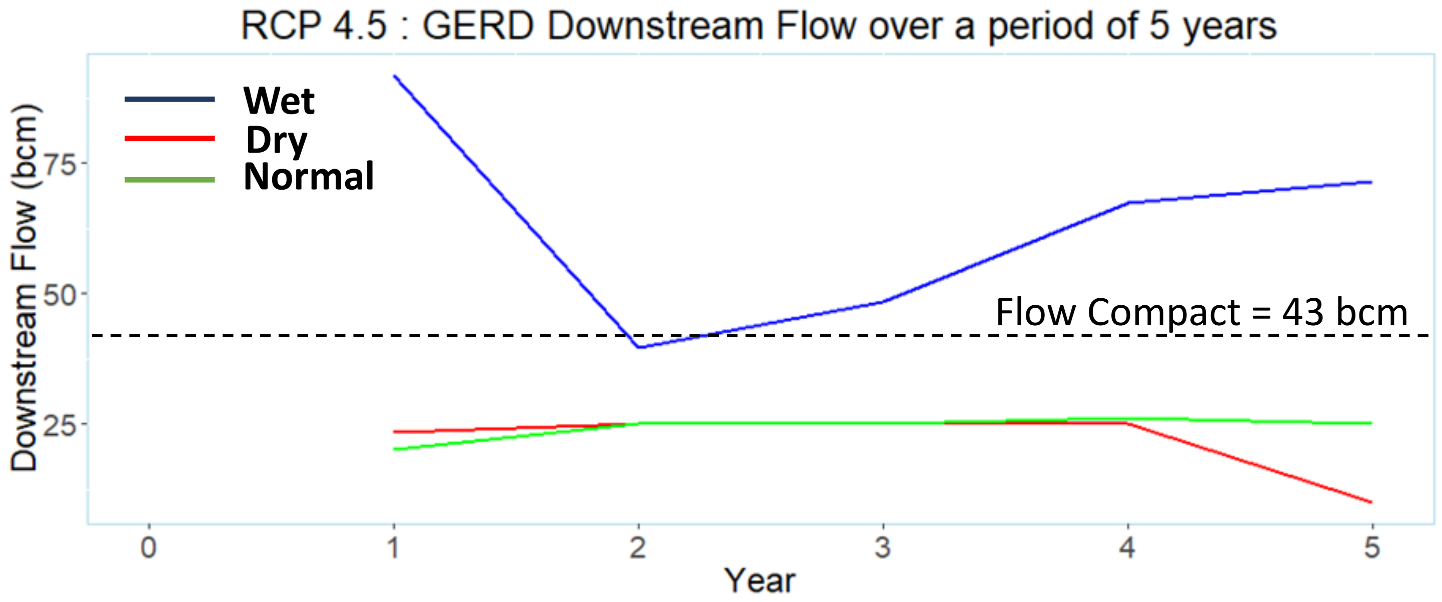
- Gamma distribution based on variance of mean annual inflow data used to represent wet, dry and normal flow conditions
- Inflow used in water balance model for each year selected at random out of the given gamma inflow distribution (wet, dry, normal)
- Uncertainty represented using Monte Carlo integration of the given distribution (still working on this part)



Results: RCP 4.5 Outcomes with 5-yr Fill Period (most aggressive)

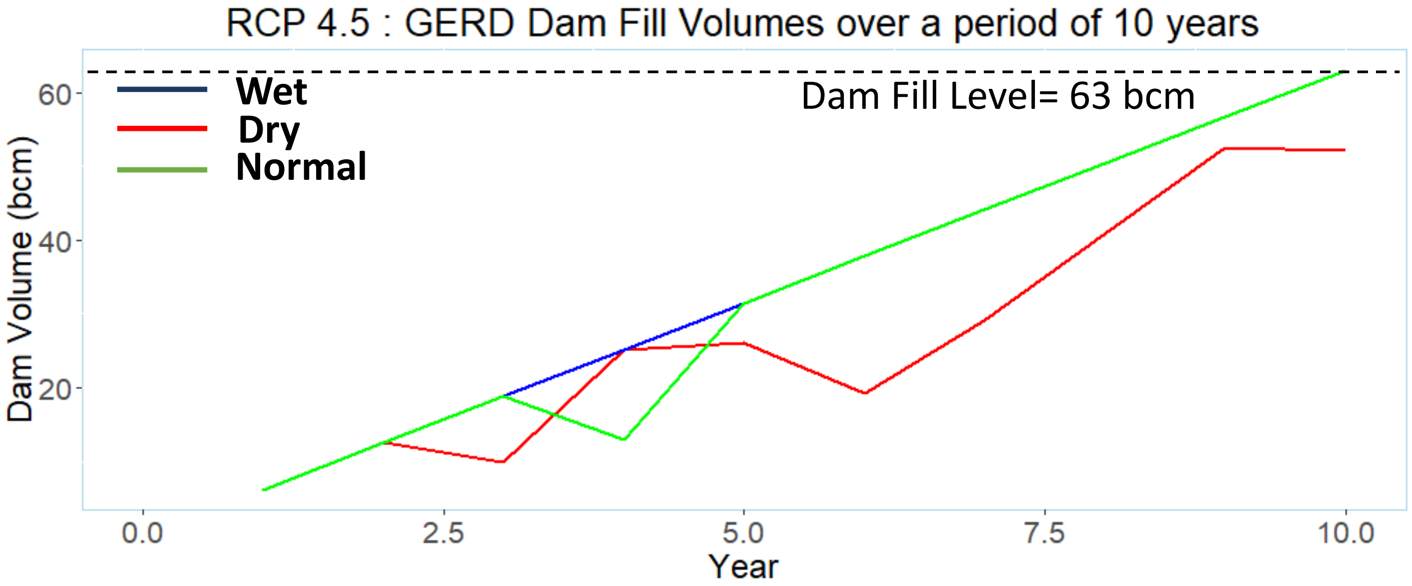
- Only the wet-biased inflow data resulted in filling dam
- Downstream Flow Compact met in most years for wet-biased inflow data
- Downstream Flow Compact never met for normal- or dry-biased inflow data

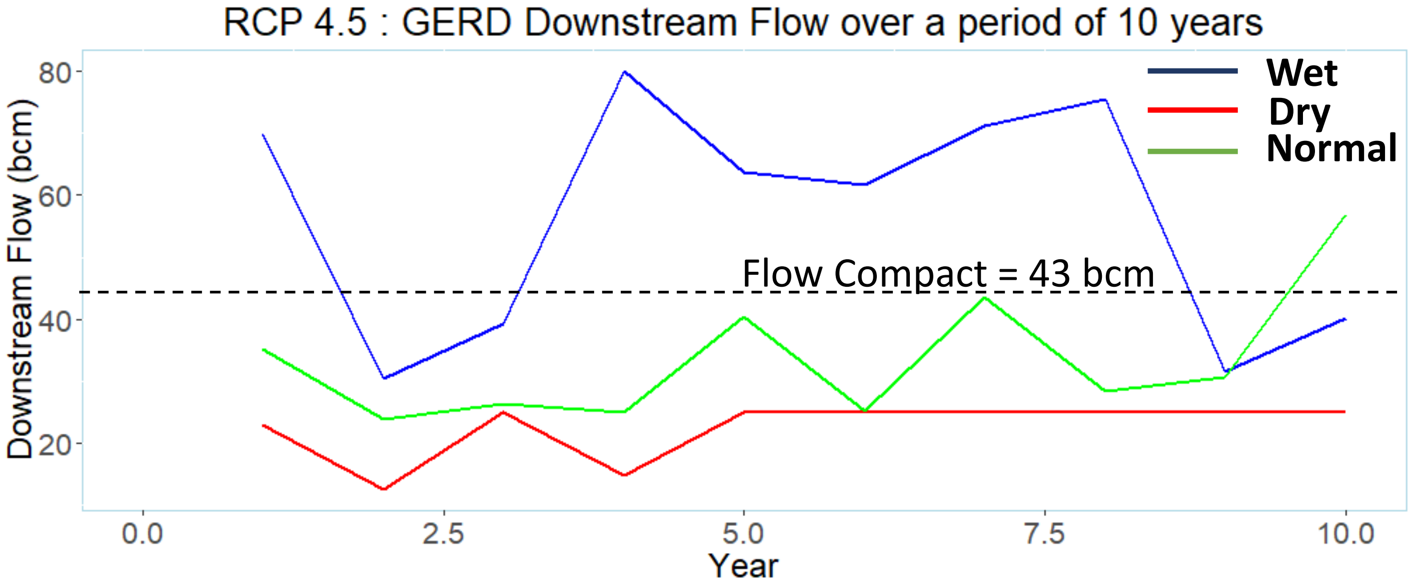




Results: RCP 4.5 Outcomes with 10-yr Fill Period

- Only the wet- & normal-biased inflow data resulted in filling dam
- Downstream Flow Compact met in most years for wet-biased inflow data
- Downstream Flow Compact never met for dry-biased inflow data & only 1x for normal-biased inflow data

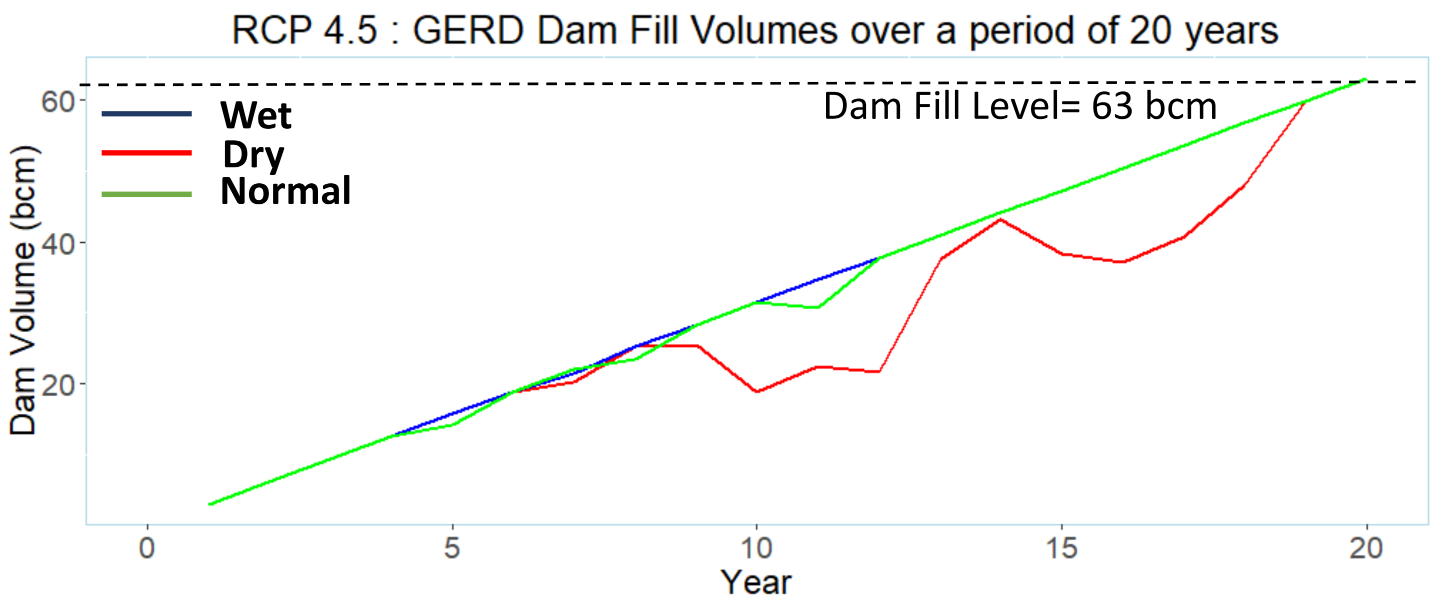


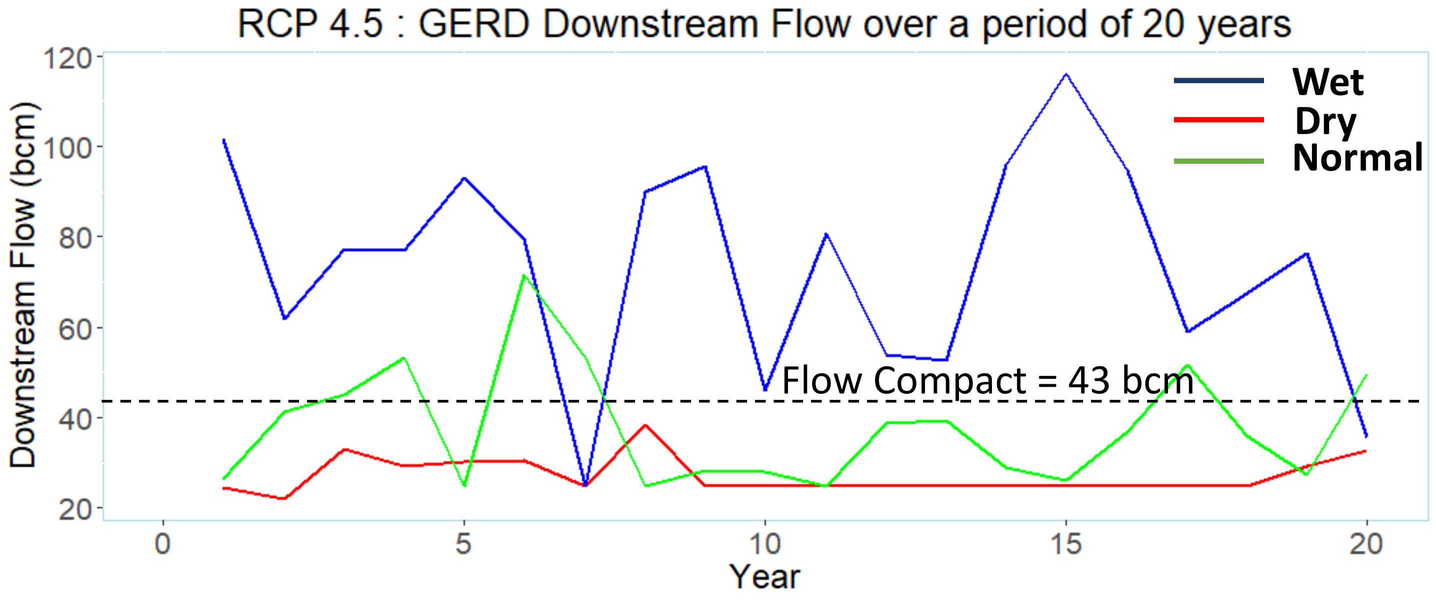


Results: RCP 4.5 Outcomes with 20-yr Fill Period (least aggressive)

Los Alamos NATIONAL LABORATORY EST. 1943

- Dam filled for all inflow scenarios
- Downstream Flow Compact met in most years for wet-biased inflow data
- Downstream Flow Compact never met for dry-biased inflow data & only occasionally for normal-biased inflow data





Conclusions

- Flow conditions (wet, normal, dry) are strong determinant of success in filling the dam
- Some improvement for longer fill periods
- Downstream Flow Compact only met under wetter flow conditions, rare otherwise
- Results generated using other inflow datasets (not shown) indicate selection of data important for filling dam and highlight difficulty in determining which one to trust

Thank You